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Wetland traction research: Present status and future need

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ABSTRACT : Wetland traction is special area in the broader field of farm mechanization research. The requirement of mechanized cultivation, especially for paddy crops has increased its importance. Trafficability of the surface soil layer of paddy field is very poor, being extremely soft with low load bearing capacity. Farm tractors and power tillers operated in these conditions require special traction devices such as cage wheel for better trafficability. A number of research works have been reported on wetland traction. These could be broadly divided into specific areas such as (a) performance analysis of cage wheels operated in wetland, (b) behaviour of soil under the action of traction device (c) new design of wetland traction device; (d) traction dynamics study and (e) optimization of design parameters. Circumferential lugs provided in the cage wheel assists traction. However, optimal design of lugs with reference to its geometry and spacing has been a major area of investigation. Deteriorating performance of cage wheel resulted by excessive sticking of wet clay has been reported through experimental investigations. Three distinct mechanisms arising from improper combination of lug spacing and wheel slip have been identified as the primary causes of excessive adherence of clay soil to metal cage wheel.Coating of the metal cage wheel using non-sticky material like enamel, to improve cage wheel performance has also been attempted with positive results at varying degree of wheel slip up to 100 per cent. The performance of cage wheel mounted with tractor was also been assessed under varying operating and design conditions. At a constant hardpan of 30 to 40 cm the increase in traction up to 59 per cent was reported due to increase in wheel diameter by 7per cent. The inflation pressure of driving tyre and forward speed did not affect the traction performance in this test. Substantial enhancement in wetland traction (up to 48% increase in draw bar pull) of power tiller by using specially designed extension strake as traction aids was reported by experimental investigation in soil bin. Enhancement of net traction of two wheel drive tractor in soft clay soil was reported with the increase in axle load. Results of the same investigation also indicated non-significant effect of tyre inflation pressure on drawbar power except at the highest ballasting of 2.2 kN on the drive axle. Further, deteriorating traction performance was reported with increase in soil moisture content due to flooding. Some studies were also dedicated to make experimental investigation of soil reaction forces on lug with varying degree of analytical support. Such studies provided useful information for designing traction aids, especially lugs of cage wheel. However, in majority of the cases optimal design parameters of traction aids are decided based either (i) on the experimental results concerning some fixed set of system parameters or (ii) optimal values obtained from statistically analyzed results of experiments. This necessitates further research work aiming to develop effective analytical tool for wetland traction.

KEY WORDS : Cage wheel, Traction performance, Lug spacing, Wheel slip, Sinkage

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The traction power developed by the tractor or power tiller is the result of interaction of traction device and soil surface. In wet conditions the stability of the aggregate is reduced, the soil becomes soft and unable to support the applied load. In these conditions wheel slip and sinkage is increased and tractive efficiency is decreased. Farm tractors and power tillers operated in these conditions require special traction aids and devices such as cage wheels for better traction. The cage wheel has been proved to be the most effective traction aid. Experiments have revealed up to three times more pull exerted by cage wheels in comparison with inflated tyres in flooded soil conditions.

Attempts have been made to optimize different parameters of cage wheel such as lug spacing, lug angle and lug dimensions (Fig A). Providing additional circumferential rings, opposing circumferential lugs and coating of the metal cage wheel with non-sticky materials like enamel has also been tested for improvement of cage wheel performance.

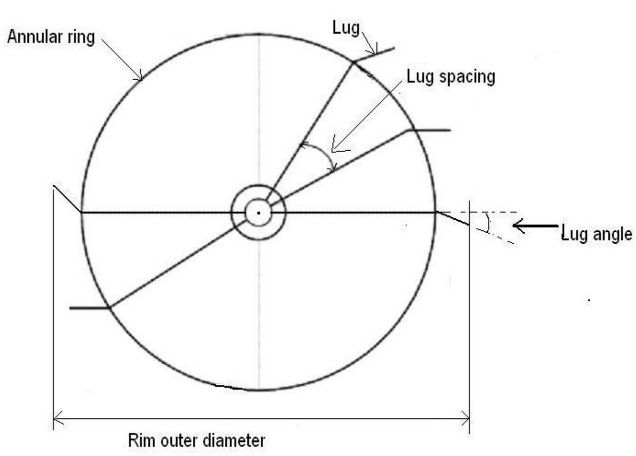

Fig. A: Schematic diagram of cage wheel showing different parameters

Performance analysis of cage wheels operated in wetland :

Experiments were conducted by different researchers to assess the performance of cage wheels in different operating conditions. Hendriadi and Salokhe (2002) investigated the traction performance of cage wheel in swampy peat soils of Indonesia where deep sinkage and high wheel slip were identified as major problems. The result revealed that increasing lug angle from 15^0 to 35^0 increased the maximum tractive efficiency by 21.68 per cent but further increase in lug angle did not improve the tractive efficiency. While increasing the number of lugs from 14 to 18 and width of lug did not improve the tractive performance significantly. The sinkage was recorded highest for 15^0 while the lowest was for 45^0 lug angle. The lug angle also affected the amount of soil interacting with the lug, which ultimately affected sinkage. A cage wheel with lug size of 325x80 mm, 35^0 lug angle, 14 lugs (26^0 lug spacing) with 2 circumferential flat rings installed on the inner side of the lugs provided better traction performance.

Gee-Clough and Chancellor (1976) studied the forces developed by a single lug of cage wheel in clay loam soil and observed that soil moisture content, lug angle, lug width, lug shape, sinkage and travel reduction had a strong effect on lug forces. Yamanaka (1962) evaluated the performance of lugs at different lug angles and concluded that a 30° lug gave higher maximum pull and lift forces as compared with other lugs. Masuda and Tanaka (1964) conducted experiments to see the effect of soil deformation and lug sinkage on the tractive performance of a lugged wheel and found that the reaction forces of a wheel varied with the deformation of the soil.

Coating of the metal cage wheel using non-sticky material like enamel, to improve cage wheel performance has also been attempted with positive results at varying degree of wheel slip. The field testing of a power tiller with enamel coated cage wheel lugs showed that the mean values of pull, corresponding to 100 per cent slip, were 6 per cent higher than that of non-coated lugs in moist soil conditions (Salokhe *et al.*, 1990).

Experiments were also conducted to study the performance of inflated tyres in wetland condition. The net traction of two wheel drive tractor in soft clay soil increased with the increase in axle load (Gholkar *et al.*, 2009). The effect of tyre inflation pressure on drawbar power was not significant except at the highest ballasting of 2.2 kN on the drive axle. Drawbar power and net traction ratio was observed to be reduced due to increased moisture content with field flooding.

Behaviour of soil under the action of traction device :

During the operation of traction device the soil behaviour such as soil adherence and blocking of cage wheel, soil compression and shear failure pattern affects the performance of traction device. Attempts were made to study the soil behaviour under the action of traction devices. Salokhe and Gee-Clough (1988) conducted experiments and resulted three possible mechanisms by which wet clay soil can adhere to metal cage wheel lugs; i) if lug spacing is high and slip medium to low then the lug behaves as though it is acting in a semi-infinite soil mass and an elliptical soil wedge forms in front of the lug. However, in subsequent passes no further soil was added to this initial build up and, therefore, this is not a likely mechanism for blocking in practice. ii) If lug spacing is low (9^0 to 12^0) and slip is high but less than 100 per cent, the soil is progressively punched into the space between lugs until this space is completely filled with soil causing blocking of cage wheel. iii) At 100 per cent wheel slip the wheel has to sink deeper and deeper into the soil on each subsequent rotation in order to generate lift force to support the weight on the wheel. On each subsequent rotation, more and more soil adheres to the surface of the lug causing most likely mechanism of cage wheel blocking in practice.

In a field experiment conducted by Jayasundera (1980) on an 11 kW four-wheel tractor, the minimum circumferential lug spacing below which wheels blocked with soil was found to be 23 cm. Similar study was conducted by Wimalawansa (1982) on a 46 kW tractor giving minimum circumferential lug spacing as 29 cm below which blocking occurred. These studies state that in a given soil condition, there is a minimum lug spacing below which a wheel will block with soil.

Salokhe and Gee-Clough (1988) studied the deformation pattern of wet clay soil under the action of multiple lugs. During study the effect of trench spacing, lug slip and lug spacing on the soil deformation and wedge formation under a succeeding lug was studied. It was observed that the soil behaviour under multiple cage wheel lugs was significantly affected by lug spacing and slip. The soil wedge formation as well as soil adhering to the succeeding lug was a strong function of lug slip and spacing. In all cases the soil deformation pattern was quite different from that caused by a single lug.

The soil deformation patterns of towed wheels are different from driving wheels. During studies on soil deformation under a lug wheel, (Tanaka, 1958 and 1959) it was observed that the resulting appearance of soil compression and shear failure pattern was different for towed and driving wheels. Wu *et al.* (1984) conducted experiment on wet clay soil with single lugged wheel and observed that the flow pattern consisted of an interface zone, a transition zone bounded by a section of a circle and the Rankine passive zone as assumed in conventional soil mechanics theory. The failure zone for multiple lugs was different than that of a single lug. Later, Salokhe and Gee-Clough (1987) observed that the soil deformation pattern in front of a single lug in wet clay soil is totally different than that assumed in the conventional theory. The deformation zone in front of a single lug consisted of an interface zone (elliptical soil wedge) and a heart-shaped zone of plastic flow. No transition zone or Rankine passive zone was observed. The number of lugs, lug angle and wheel slip had significant effect on soil failure pattern. Gee-Clough and Chancellor (1976) and Deng and Youg (1984) observed that if the lug entry angle is relatively small, then immediately after lug engagement with the soil, the soil failure pattern is a predominantly vertical failure pattern which changes to a horizontal failure pattern as the angle of rotation of the lug increases. Deng and Youg also concluded that thrust of the driving wheel depends on the shear characteristics of the soil.

New design of wetland traction device :

The power tiller tyres fitted with extension strake as traction aids were studied by Sirohi (1991) for the assessment of tractive performance. They found that the tractive capacity of power tiller fitted with extension strake, especially in loose soils, has increased substantially. Extension strakes increased the drawbar pull by 47.6 per cent in loose soil.

Attempts were also made to improve the tractive performance of cage wheels with opposing circumferential lugs. Watyotha and Salokhe (2001) tested the performance of cage wheels fitted with opposing circumferential lugs. The wheel developed the peak power at about 30-40 per cent slip depending on the circumferential angle and lug spacing. The tractive efficiency decreased continuously as circumferential angle increased from 0 to 45^0 at all spacings. The lug spacing had a significant effect on the tractive efficiency at 45^0 circumferential angles only. The modified wheels with 15^0 circumferential angles at 24 and 30^0 lug spacings showed significantly higher tractive power compared to other combinations. Although the power of the modified wheels was higher than that of the conventional wheels, the traction efficiencies between the modified and normal wheels were not significantly different.

The experiments conducted by Chen and Chao (1984), Gee-Clough (1981), Hermawan *et al.* (1996), Jayasundera (1980), Pandey and Ojha (1978), Salokhe *et al.* (1989), Watyotha *et al.* (2000) and Wimalawansa (1982) revealed that the factors affecting the performance of cage wheel are lug angle, lug spacing, lug size, lug shape, lug sinkage, lug mechanism and circumferential angle. The study on lug configuration like a rubber tractor tyre on the cage wheels, called opposing circumferential lugs, was carried out by Watyotha (2000). The pull and lift forces of the modified wheel were significantly higher than those of the conventional wheel. Moreover, the variation in wheel forces of cage wheels with opposing circumferential lugs was not only lower than that of conventional or normal wheels but also lower than cage wheels with circumferential lugs.

Another new design of cage wheel having movable lugs using a rollers-sliding groove mechanism was designed and tested by Hermawan *et al.* (1998). The sinkage of movable lugs was reduced for the same vertical load as compared with fixed type. The pull and lift forces obtained by the movable lug were higher than those obtained with the fixed lug. Later a theoretical analysis of soil reaction forces of movable lug cage wheel was made by the same authors. The superiority of the pull and lift forces of the movable lug cage wheel compared with those of the fixed lug wheel were supported by the theoretical analysis.

Traction dynamics study :

The dynamic behaviour of an open lugged cage wheel under paddy soil condition has been studied by Wang *et al.* (1995). The same authors conducted experiments in 1995 with the cage wheel which was free to sink under load. Three different test soil conditions were used for the experiment. Test soil conditions I and II had a uniform soft layer of soil with average moisture contents of 19 per cent and 41per cent (d.b.), respectively. Test soil condition III had a soft soil upper layer of 90 mm and a hardpan layer of 260 mm depth, with moisture contents of 55 per cent and 30.1per cent (d.b), respectively. The most interesting result was observed in the experiment conducted under test soil condition III with a hardpan. The results show the important points as follows:

- The normal soil reactions on the lug had two extreme values while the lug passed through the soil. This is different from the results reported in the past.
- The pattern of soil reactions on the lug under paddy soil conditions with a hardpan showed distinct differences to that of the other test soil conditions without a hardpan. The soil reactions on the lug under test soil condition II (higher moisture content)

showed a smooth curve. Under the test soil condition III (having hardpan), the differences of the soil reactions between the soft upper layer and hardpan were shown clearly.

– Pull and lift forces of the lugged wheel, obtained by lugs contacting the soil, fluctuated periodically with lugged wheel rotation, corresponding to the angle between adjacent lugs. Consequently, there was a fluctuation in the slip and sinkage of the lugged wheel.

Field experiments of lugged wheels with rims were conducted by Hashiguchi *et al.* and the soil reactions to the lug and the rim were measured. However, since most of these were carried out under predetermined slip and sinkage conditions, their applicability to the design of lugged wheel is questionable. The actual motion of a freely sinking lugged wheel is determined by the interaction between the lugs contacting the soil and the soil beneath the lugs, with some load on the axle of the wheel. Theoretical analysis and experiments were carried out with several vertical and drawbar loads applied to the axle of the lugged wheel in the laboratory, using a soil bin and experimental facility. It was found that, as the lugged wheel rotates, slip and sinkage of the wheel fluctuates periodically corresponding to the angle of adjacent lugs (Wang *et al.,* 1995). They also studied the dynamic behaviour of cage wheel and found that the slip and sinkage fluctuating periodically with the rotation angle and the period was equal to the interval of lug spacing. The fluctuation of slip and sinkage led to variations of motion of the axle and the locus of lugs in the soil.

Optimization of design parameters :

A number of studies were carried out to optimize the design parameters for improvement of traction performance of cage wheels. Pandey and Ojha (1978) carried out a dimensional analysis to study the effect of individual wheel parameters on the traction performance of rigid wheels in saturated soils. Through the regression analysis, the optimum values of lug angle, rim width and lug spacing were found to be 20°, 200 mm and 110 mm, respectively for a wheel of 685 mm dia. However, a definite conclusion regarding the optimum value of lug height could not be drawn in this study. Wu *et al.* (2004) evaluated the cage wheel as a traction aid with driving tires of agricultural tractors in wet soil condition and showed that the cage wheel increased the traction performance of the tractor as the diameter of the cage wheel increased. The peak torque required by a single lug increased by 5 per cent as the diameter increased from 1182 to 1222 mm and by 17 per cent as it increased to 1262 mm. Increasing the number of lugs increased the traction developed by the cage wheel. However, the traction developed by individual lugs decreased due to their interferences.

The study for optimization of circumferential angle and lug spacing was carried out by Watyotha *et al.*(2001). The experiment resulted that the magnitude of variation in lug wheel forces depends on circumferential angle and lug spacing. The variation in lug wheel forces can be reduced by increasing the lug circumferential angle however additional measures will have to be taken to eliminate the resulting side forces.

Gee-Clough and Chancellor (1976) observed that soil moisture content, lug angle, lug width, lug shape, sinkage and travel reduction had a strong effect on lug forces and found to be in reasonable agreement with the forces predicted by using the passive soil failure theory developed by Hettiaratchi *et al.* (1966). Jayasundera (1980) evaluated the performance of cage wheel and found that a cage wheel of 0.88 m diameter with a lug of 0.10 m height gave optimum efficiency at about 30^0 lug spacing and 30^0 lug angle. Triratanasirichai and Oida (1990) tested and suggested the best combination of lug angle and lug spacing for maximum tractive efficiency in sandy soil and paddy field conditions. Lu *et al.* (1992) studied the dynamic performance of a single lug and found that an increase in the lug angle caused a slight decrease in the efficiency when slip was less than 25 per cent and caused a slight increase in the lug efficiency at slip larger than 25 per cent.

Conclusion :

In majority of the cases optimal design parameters of traction aids are decided based on the experimental results concerning some fixed set of system parameters such as lug angle, lug dimension, number of lugs, additional circumferential rings on cage wheel, coating cage wheel with non-sticky material, tyre inflation level, movability of lug, lug orientation and fitting extension strakes. The other considerations are the optimal values obtained from statistically analyzed results of experiments. This necessitates further research work aiming to develop effective analytical tool for wetland traction.

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